

Shuttle Program

Formulation, Development and Operations

Master Forum # 20

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Space Shuttle

A Real Experience and Great Machine



Introduction

- Panel members
 - Tom Moser – Program Mgt. and Orbiter Dev.
 - Jody Singer – Propulsion Systems Dev.
 - Russell Rhodes – Launch Ops.
 - Frank Buzzard – Reflections of Chief Engr.
 - John O'Neil – Mission Ops.
- We have a lot to share and a little time
 - 30 minutes for each to speak
 - 15 minute Q&A for each segment

Passing the Torch

Five Lessons Learned

- “Political Systems Engineering” has and will continue to increase.
- Freeze the configuration but not the program plan
- Simple system interfaces simplify program management and reduce risk
- “Better is the enemy of good”
- Operational flexibility cover development short falls.

Program Management and Orbiter Development

- Transitioning from Apollo era to Shuttle era
 - Huge difference in technology challenges and the political environment
- Early Shuttle program formulation
 - Studied many options
 - Froze the configuration but not the development program
- Orbiter systems development
 - Simplify system interfaces
- Early operations
 - Operating to stay within the capabilities
 - Moving from development into operations

Transitioning from Apollo Era to Shuttle Era

- Program management challenges were very different because of
 - The political environment
 - Bureaucracy and oversight increased
 - The technology requirements
 - Technology issues decreased
 - The need to keep the program “sold”
 - A new challenge

Changes in the Political Environment

- Different political environment
 - Apollo – The Presidents program, full political support, money was not an issue, very little oversight, schedule driven.
 - Shuttle – “Sold” to the White House, fragmented political support, money was tight, schedule was a variable, more bureaucracy
 - Apollo program management could focus on
 - Organizing and managing the government and industry team
 - Developing technologies

Technology Challenges

- Technology
 - Apollo – “We did not know what we did not know”, numerous and huge technology and ops challenges
 - Shuttle –Major developments
 - Propulsion systems
 - Thermal protection systems
 - Avionics
 - Reusability
 - Shuttle Program Management had to balance technology and “routine” ops challenges

Continuously Selling the Program

- Keeping the program “sold”
 - Apollo – Not an issue
 - An excited public, Congress and White House
 - Many frequent events to show progress
 - Shuttle – A continuous challenge
 - Funding was tight and the mission objective was not as dramatic
 - Years of development with no “gee wiz” events until the Orbiter Approach and Landing Tests
 - The last two years the objective was to get the “SoB” in Space
 - Program Management had to re-plan schedule and content every year.
 - Increased communications up to keep the program sold and down because of a frustrated team

Transitioning from Apollo era to Shuttle era

- There seems to be a “Conservation of program management complexity”
 - Apollo had extreme technical and management challenges but was simple politically.
 - Shuttle had fewer technical and management challenges but many political challenges.
- “Political Systems Engineering” became a new and required skill for Shuttle program management.

Program Management and Orbiter Development

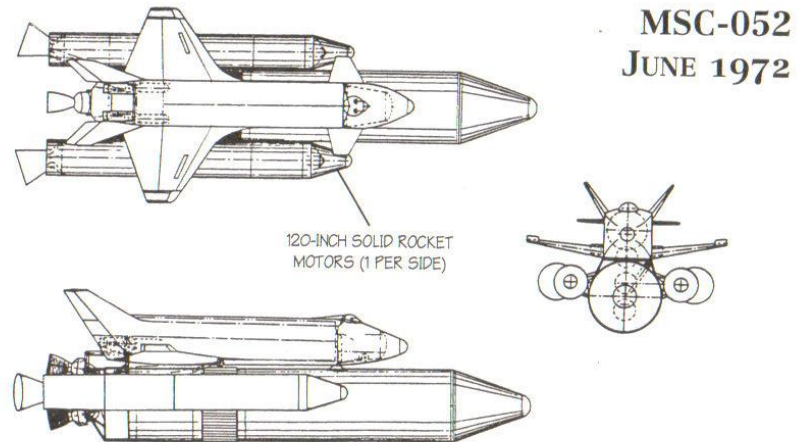
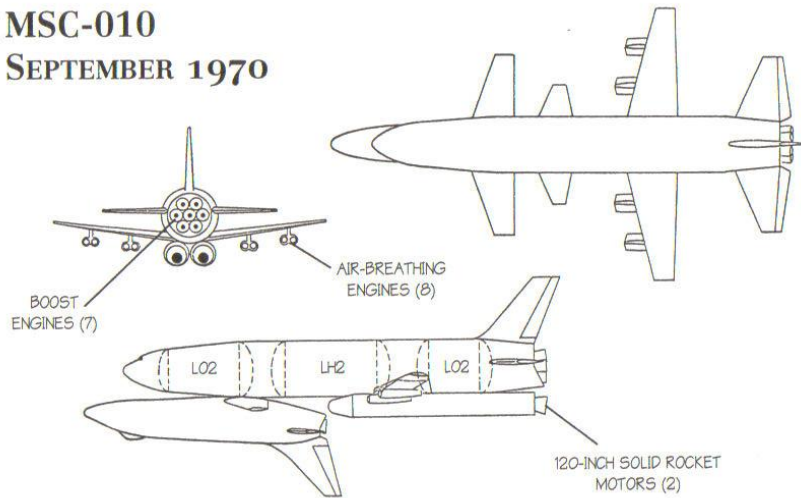
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Shuttle Program Design Variables

- Earth-to-Orbit Transportation System
- Multi-year budgets
- Development and ops costs
- Payload mass and size (delivery and return)
- Operational orbits
- Fully or partially reusable flight systems
- Turn-around time
- Entry cross-range

Shuttle Configurations

MSC-010
SEPTEMBER 1970



Early Shuttle program formulation

- Developing requirements and options
 - Phase A/B – Establish the configuration and top level requirements
 - Phase C/D – Establish the design details and derived requirements
- The balance was between development and operations costs
 - The program had to fit within the annual projects funds available
 - Operations costs suffered

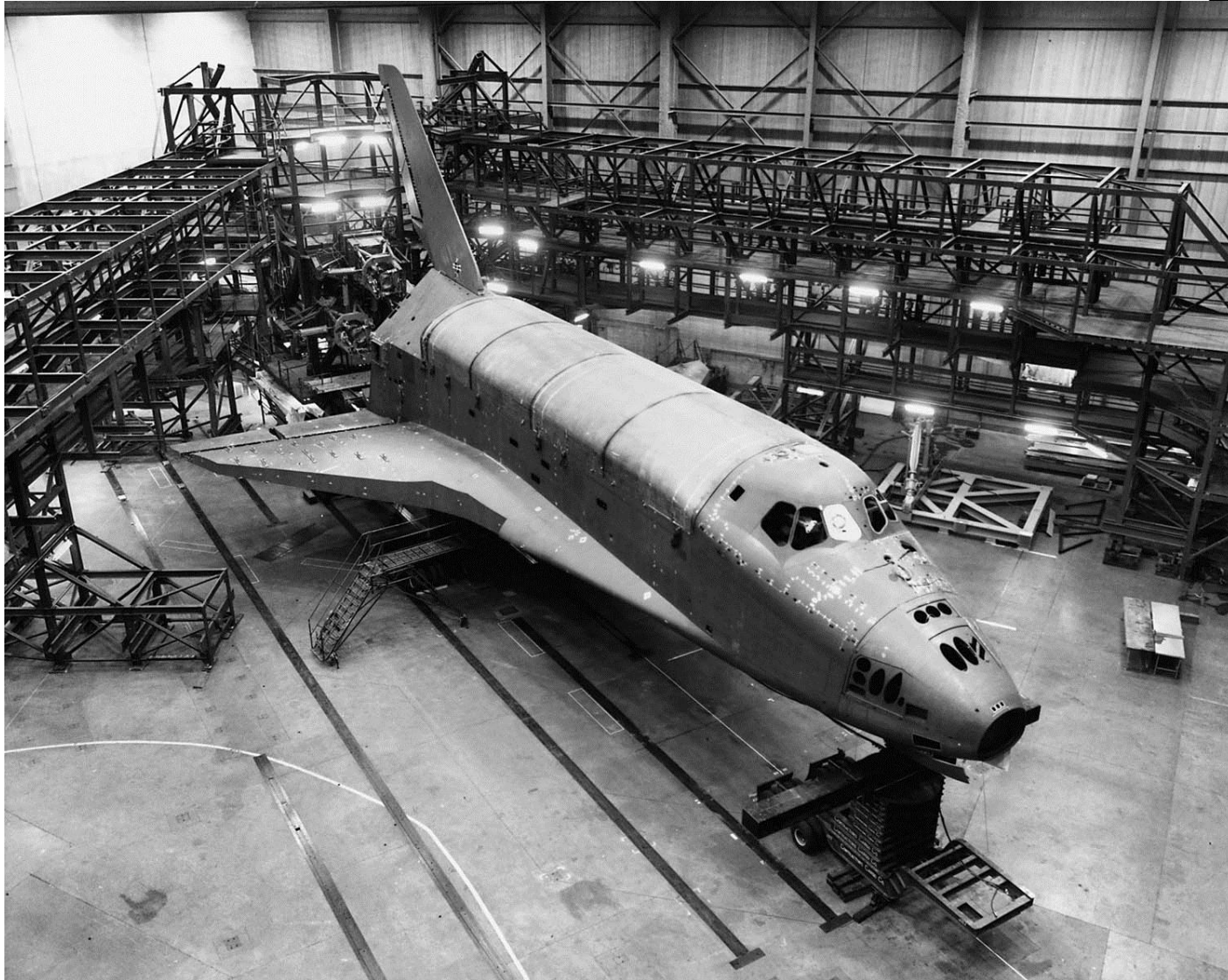
Early Shuttle program development

- The Baseline Design did not change
 - The development of the four Shuttle flight elements proceeded in parallel
 - The Orbiter was developed for the original costs estimate of \$5 billion because
 - Many and continuous changes were proposed but denied
 - Some subsystems were changed to “make work” and reduce weight and costs, but with no impact on other subsystems
- Orbiter Project management philosophy:
 - “Better is the enemy of good”
 - “The most innocuous change is the most far reaching”

Managing the Program by Changing Plans not Configuration

- The Orbiter certification plan evolved to accommodate budget reductions
 - Full-up systems Thermal Vacuum tests of the forward and aft fuselage eliminated
 - Component TV tests performed
 - Full system analyses performed
 - Early flights designed to be benign, verify analyses, and gradually “open the envelope”
 - Two Orbiter airframes for strength and life verification were eliminated
 - The *Challenger* airframe was tested to 120% of mechanical design loads and later used as a flight vehicle
 - Structural analytical models were verified
 - Thermal “loads” were added analytically
 - Smaller acoustic fatigue tests were conducted for life certification
 - Flight certification and safety were never compromised

Structural Test Article- *Challenger*



Program Management and Orbiter Development

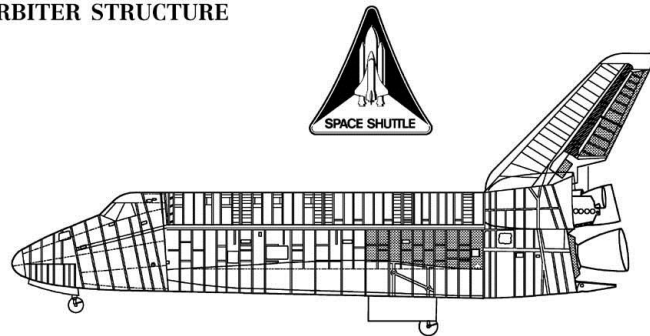
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Orbiter Development

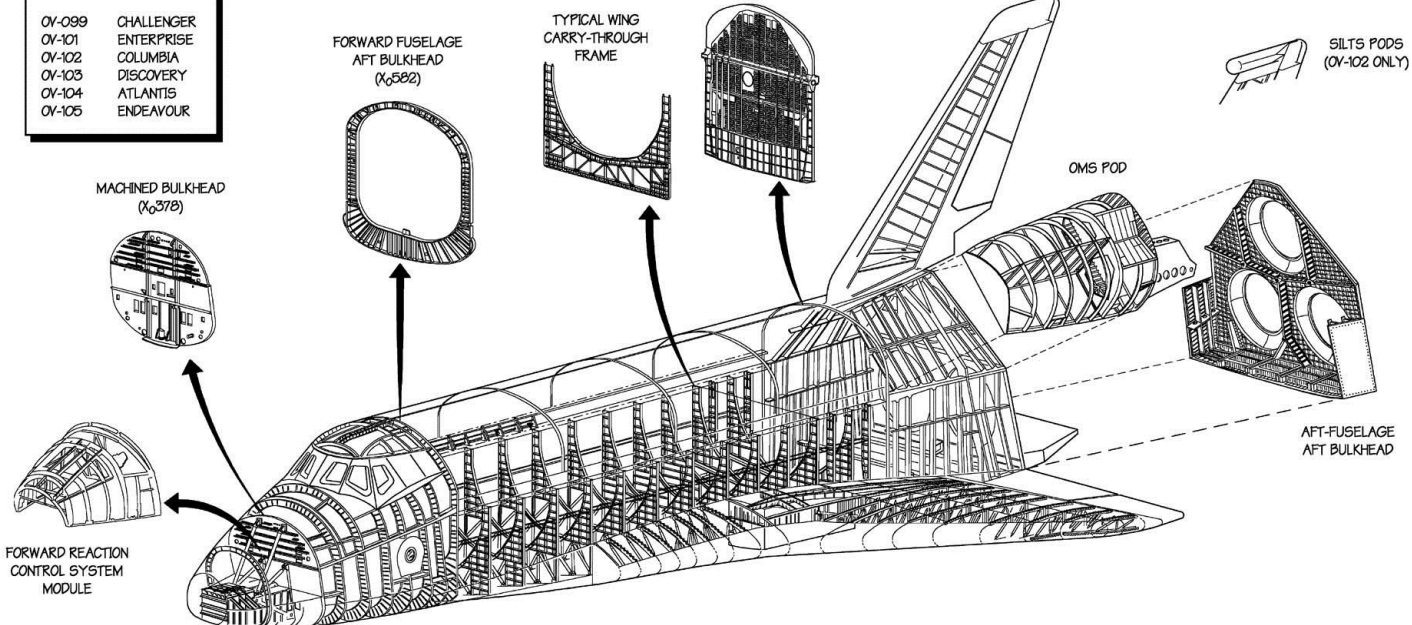
- Simple Structural Interfaces
 - Payloads in the Orbiter payload bay
 - Decoupled the structural design of the Orbiter and the Payload by having a “statically determinant” attachments
 - Moveable attachments enabled a combination of 10 million payload elements, sizes, masses, and C.G. locations
 - Crew Cabin in the Forward Fuselage
 - The CC was designed to “float” in the fuselage
 - This simplified the design of the crew cabin to that of a pressure vessel and increased the reliability with pressure tests.
- Simple interfaces and parallel development reduced program management complexity

Structure Configuration

ORBITER STRUCTURE

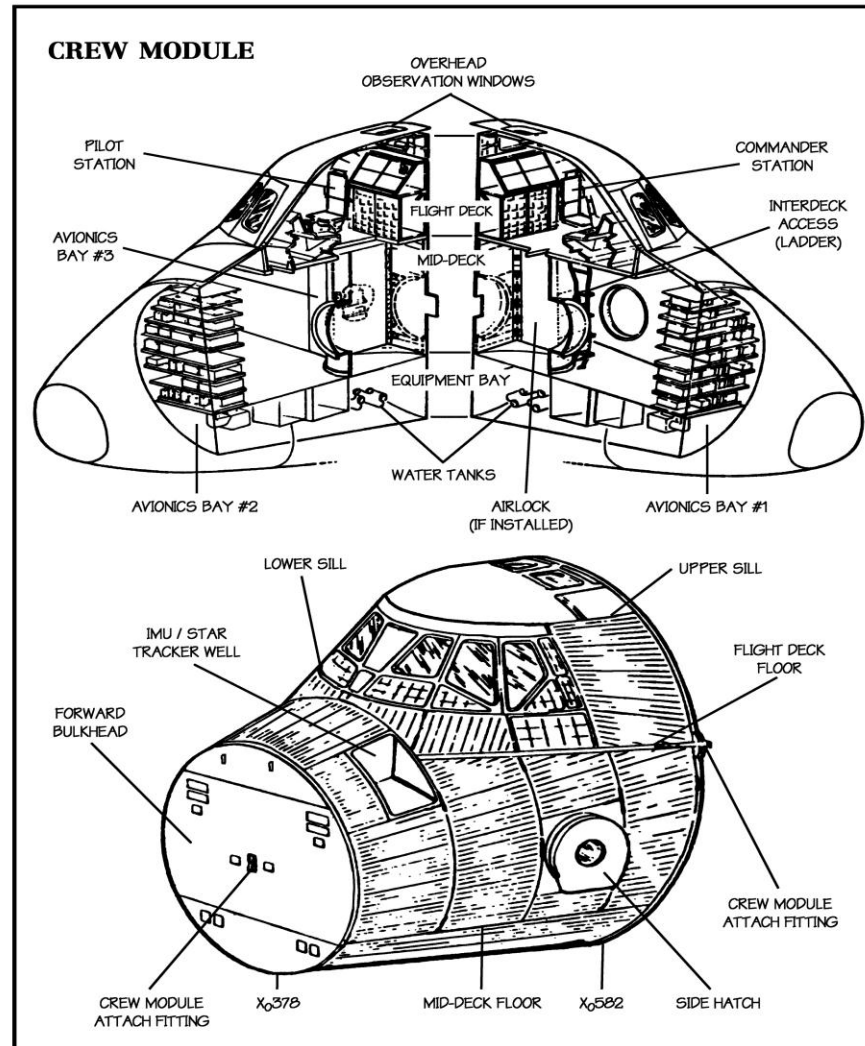


ORBITERS	
OV-099	CHALLENGER
OV-101	ENTERPRISE
OV-102	COLUMBIA
OV-103	DISCOVERY
OV-104	ATLANTIS
OV-105	ENDEAVOUR



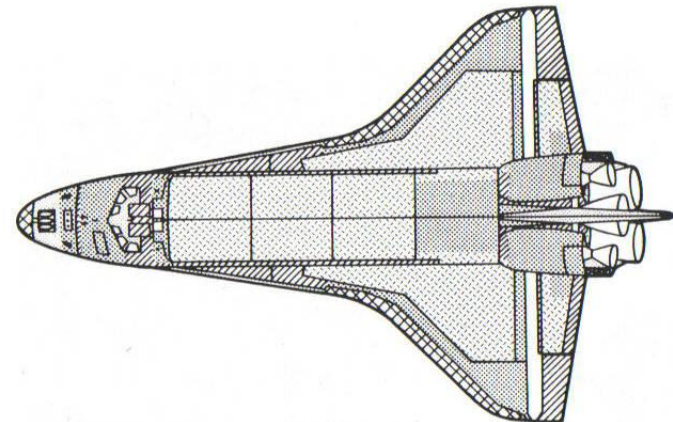
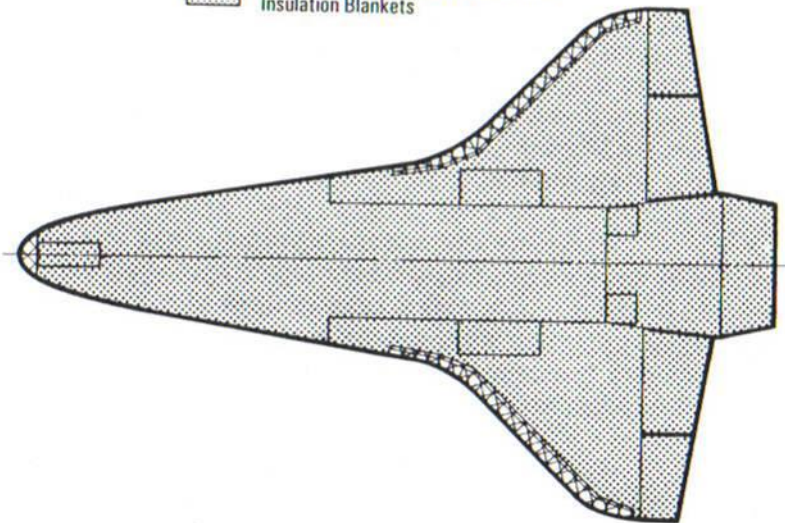
Crew Cabin in Fuselage (Simple Interface)

- Pressure vessel design
- Four discrete attachment points with the forward fuselage
- Minimum heat transfer to Crew Module
- Fracture mechanics – leak before rupture

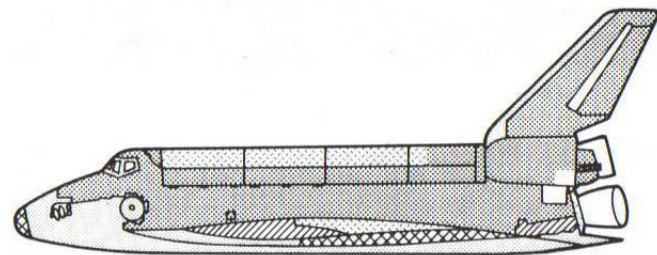


Orbiter Thermal Protection System

-  Reinforced Carbon-Carbon
-  High-Temperature Reusable Surface Insulation Tiles and/or Fibrous Refractory Composite Insulation Tiles
-  Low-Temperature Reusable Surface Insulation Tiles
-  Nomex Felt Reusable Surface Insulation
-  Metal or Glass
-  Advanced Flexible Reusable Surface Insulation Blankets



Top View



Side View

Tile to Structure Interface

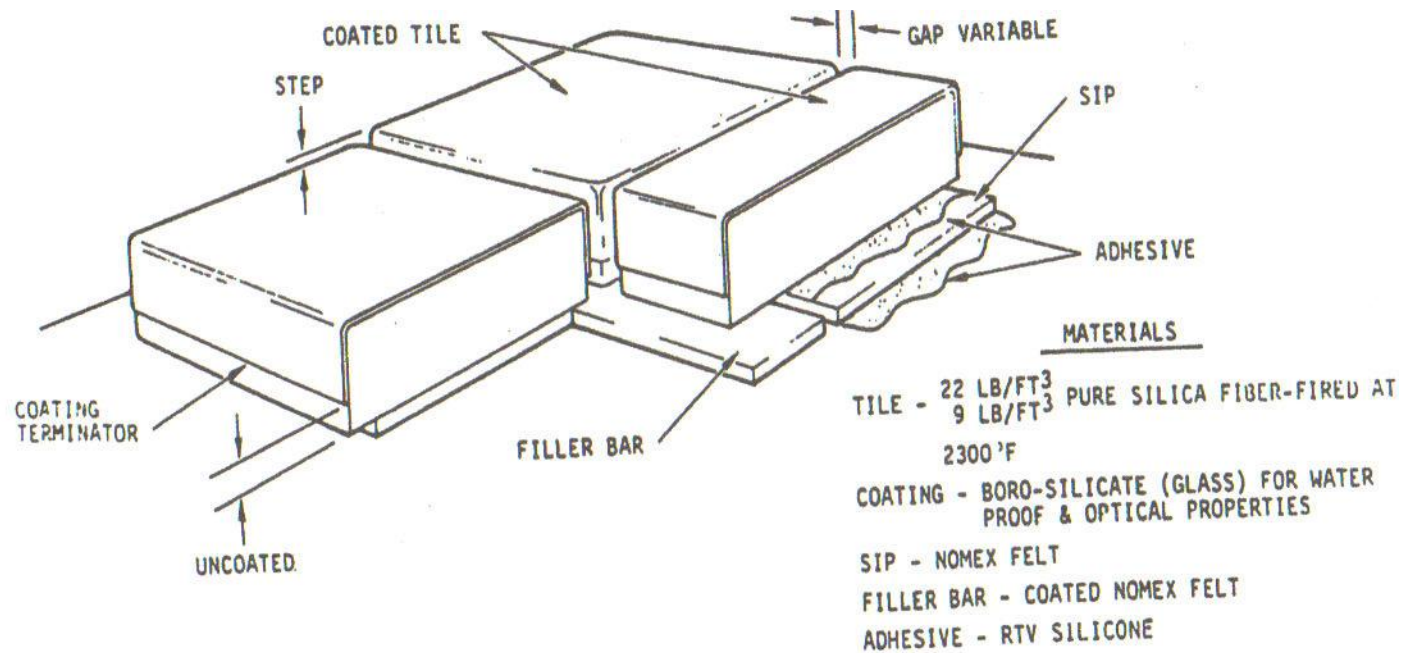


Figure 7.- Tile design.

Complex Interface

Big Program Management Issue

Structural Deformation

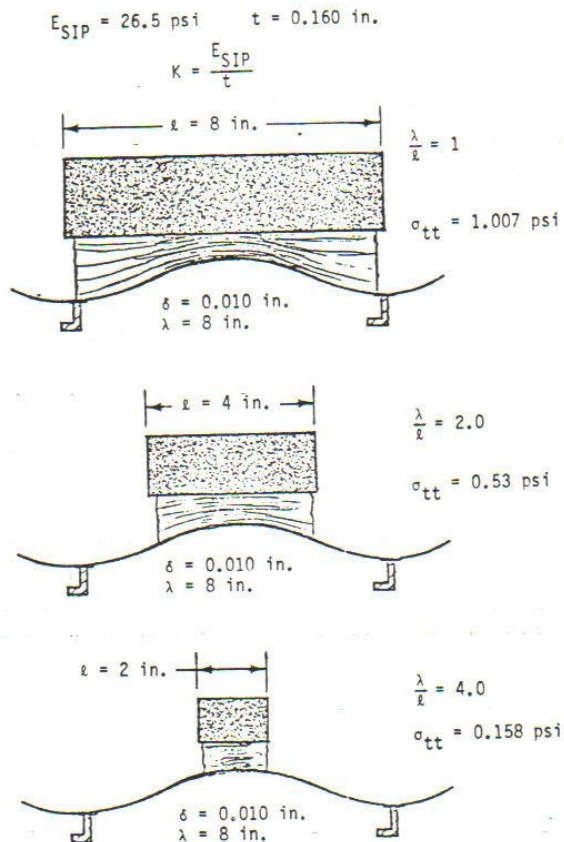


Fig. 6 Effects of substrate deflection.

Pressure Distribution

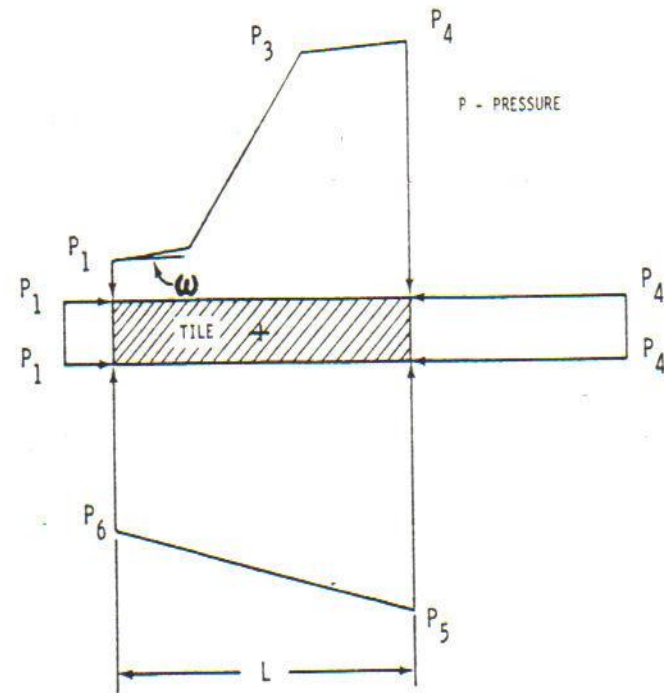


Fig. 7 Aeroshock freebody model for air loads.

Orbiter Lesson Learned

- Simple interfaces simplify program management
 - Orbiter to ET
 - Payload to Orbiter
 - Crew Cabin to Fuselage
 - TPS tiles to Orbiter

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Wing Load Surprise on STS-1

- Wing loading during ascent was greater than expected
 - The center of aerodynamic pressure was further aft and outboard
- How to proceed?
 - Placard ascent flight parameters to stay within the structural capabilities of the wings.
- Lesson learned: Ops guys sometimes have to save the development guys' A - -.

Fuel Cell Surprise on STS -2

- Problem: Debris clogged the line, shut down one of three fuel cells, and terminated the mission early.
- Fix: Put a debris filter in the line.
- Better fix: Put in two debris filters.
- Wrong: Hydrogen gas was trapped between the two filters and injected into the reservoir. We had a potential bomb on the Orbiter.
- Lesson learned: One filter was good. Stick with the principle that “Better is the enemy of good”.

Planning for Spares

- A new challenge for Shuttle management:
 - Planning and providing operational spares for a reusable fleet of vehicles
 - Primarily determining the failure rate, warehousing, and funding.
 - Early Shuttle flights had to obtain spares from cannibalizing vehicles on the assembly line
- Lessons learned: Logistics is not “sexy”, but it is necessary for efficient operations.

Spares for Facilities in Space

- A large Systems Engineering challenge
 - If the facility is to be “available” for operations 90% of the time
 - Every operating system, subsystem, or component has to be “system engineered” to be compatible with
 - Limited storage of spares at the facility
 - Limited crew time for repairs
 - Limited transportation to the facility
- Lesson learned:
 - Establish the “availability” requirements for every “black box”
 - Determine the optimum solution of how many spares, where to store, maintenance manpower, and costs.

Shuttle “Ham & Eggs Society”

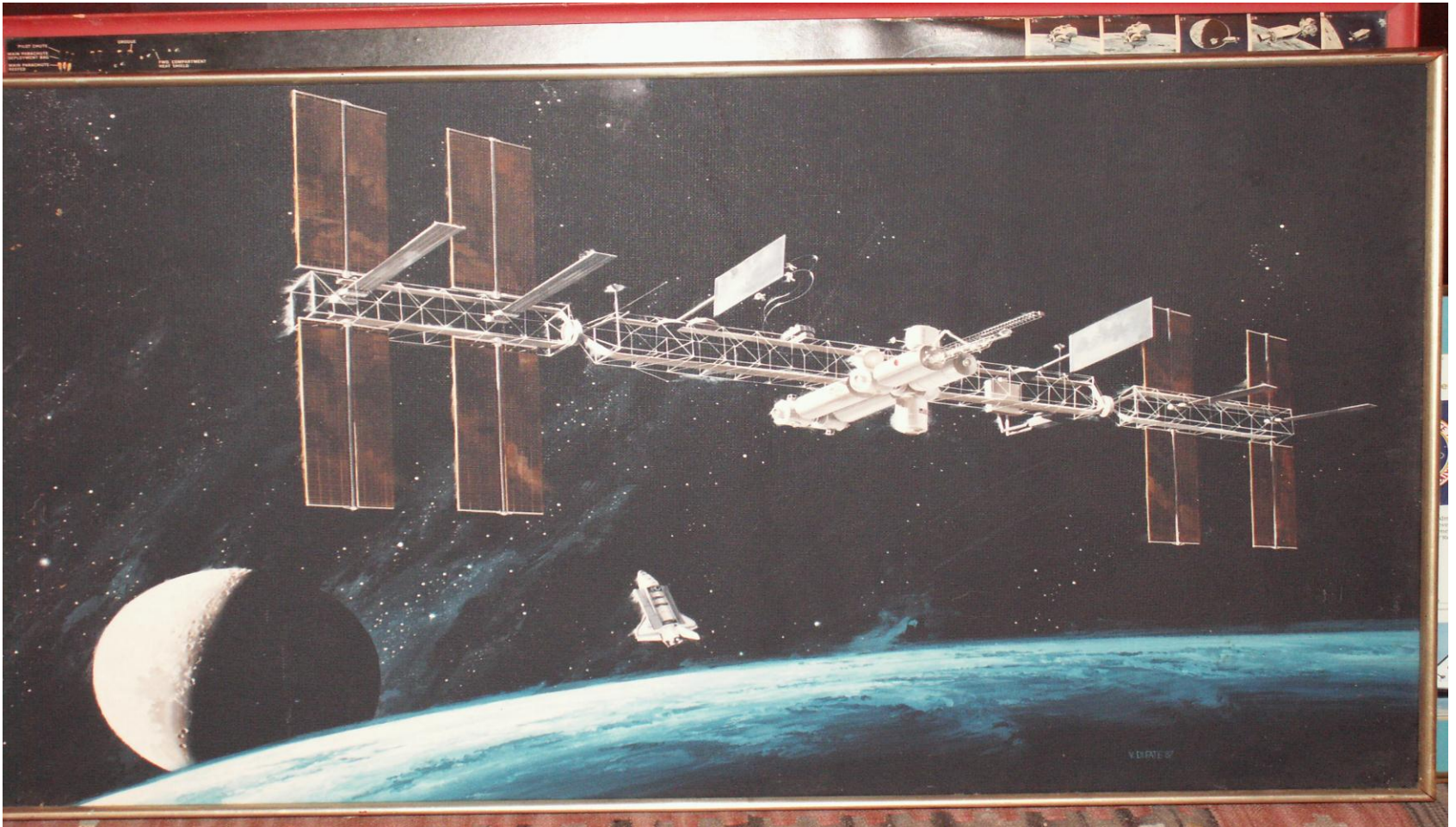
A successful Program Manager needs a fully committed team.



Space Station

- To date this had been the ultimate in changes required for the program to be successful
- Everything has changed
 - Program Management
 - Baseline configuration
 - Program partnership
 - Budgets and Schedules
 - Logistics

Space Station - 1990



Managing Program Changes

- Macro changes in NASA programs
 - Small changes in Mercury, Gemini, Apollo, Shuttle
 - Large changes in Space Station
 - Huge changes in Constellation
 - Changes will occur in future programs
- Make progress, but anticipate change